STRANGENESS ENHANCEMENT IN HEAVY ION COLLISIONS

A. Capella

Laboratoire de Physique Théorique et Hautes Energies*

Université de Paris XI, bâtiment 211, 91405 Orsay Cedex, France

Abstract

The enhancement of strange particle production observed in nucleus-nucleus collisions at CERN is explained by the combined effect of the increase in the relative number of strings containing strange constitutents at the ends, and the final state interaction of co-moving secondaries : $\pi + N \to K + \Lambda/\Sigma$.

LPTHE Orsay 94-113

December 1994

* Laboratoire associé au Centre National de la Recherche Scientifique - URA 63

An increase of the ratio R of strange over non-strange particles from nucleon-nucleon to central nucleus-nucleus collisions, as well as its increase with centrality, is now firmly established by several CERN and AGS collaborations. In the framework of independent string models such as the Dual Parton Model (DPM) and Quark Gluon String Model (QGSM), an increase of R can be partially understood in the following way[1][2]. When the average number of collisions per participant nucleon increases, the excess of produced particles is due to the fragmentation of strings involving sea constituents at their ends. Since strange quarks are present in the nucleon sea, the ratio of strange over non-strange secondaries will also increase. The size of this increase depends on the ratio

$$S = \frac{2(s+\overline{s})}{u+d+\overline{u}+\overline{d}}$$

in the nucleon sea. It turns out that the value $S = 0.5$ used in conventional parton distributions for DIS[3] allows to understand the observed enhancement of K^-, but not those of K^+ and K_s^0. Moreover, the enhancement of Λ and $\overline{\Lambda}$ is negligeably small. Two approaches have been proposed in order to overcome the latter problem. In DPM, diquark-antidiquark pairs have been introduced in the nucleon sea - with the same ratio, relative to quark-antiquark pairs, as in the string breaking process[2]. The second approach, introduced by several authors, is string fusion[4,5]. Both mechanisms have a common caveat, namely, they lead to the same increase in absolute value of strange baryons and antibaryons - which is ruled out by experiment.

In the following, we shall see that the introduction of diquarks in the nucleon sea mentioned above allows, with the help of simple quark counting arguments, to account for the observed enhancement of $\overline{\Lambda}$ and $\overline{\Xi}$. However, the multiplicity of produced Λ's is too small - by more than a factor of two. The missing numbers of Λ's and kaons are approximately the same. Thus, some other mechanism is needed which increases the number of Λ's without increasing the number of K^-

and $\overline{\Lambda}$. A simple and well known way to do so, is by a final state interaction $\pi + N \to K + \Lambda/\Sigma$. Since at CERN energies the observed enhancement is very important at mid-rapidities, the final state interaction cannot be an intranuclear cascade. One needs a genuine final state interaction of co-moving secondaries. This interaction also plays a crucial role in hadronic gas models[6] and has been incorporated into several Monte Carlo codes[5][7][8].

In this note I will show that the observed enhancement of strange mesons and baryons/antibaryons can be understood by the combined effect of strange sea quarks and antiquarks and the final state interaction mentioned above. For simplicity, I shall concentrate on the strangeness enhancement from NN to central SS collisions. In order to describe the underlying physics in the most transparent way, I consider a simplified version of the DPM with only two strings for each NN collision and make some simplifying assumptions in the fragmentation functions (see below). The aim is not to reproduce the data in the best possible way, but to present a plausible and, hopefully, convincing scenario of strangeness enhancement consistent with the experimental findings.

As a further simplification, I take the configuration with an average number of $\overline{n}_A = 24$ participant nucleons in each nucleus as representative of a central SS collision. In this case the average number of collisions is $\overline{n} = 53$*. The DPM formula for the average multiplicity of particle i in AA collisions is then[9]

$$n_i = 2\overline{n}_A \ N_i^{(qq)_v - q_v} + 2(\overline{n} - \overline{n}_A) \ N_i^{q_s - \overline{q}_s} \tag{1}$$

where $N_i^{(qq)_v - q_v}$ and $N_i^{q_s - \overline{q}_s}$ are the corresponding average multiplicities of valence qq-q and sea q-$\overline{q}$ strings, respectively. The total number of strings is $2\overline{n}$ (two for

---

* These average values are obtained in the DPM based IRIS Monte Carlo, for events with n_A and/or $n_B \geq 27$. I thank J. P. Pansart for giving me access to his code and A. Kouider for running it.

each NN collision), out of which $2n_{\overline{A}}$ involve the valence quarks and diquarks of the participating nucleons. The average multiplicity in NN collisions is $2N^{(qq)_v - q_v}$. Numerical calculations in DPM show that the increase in the number of Λ and $\overline{\Lambda}$ from NN to SS at 200 GeV/c per nucleon is roughly equal to half of the total average number of participating nucleons - in our case 24. (The average mass of the q_s-$\overline{q}_s$ strings is too small to produce Λ-$\overline{\Lambda}$ pairs at CERN energies). For kaons, this increase turns out to be somewhat larger (approximately by a factor 28), due to the kaons produced in q_s-$\overline{q}_s$ strings. This enhancement factor increases with decreasing values of the mass of the produced particle. (This could explain the observed decrease of the ratio $(n_\rho + n_\omega)/n_{charged}$ with increasing centrality[10]).

The DPM results for the number of lambdas and kaons in SS central collisions at CERN can thus be summarized as follows

$$n_{\Lambda(\overline{\Lambda})} = 24 n^{NN}_{\Lambda(\overline{\Lambda})} \tag{2}$$

$$n_{K^{(i)}} = 24 n^{NN}_{K^{(i)}} + 4 n^{NN}_{K} \tag{3}$$

where n_i^{NN} are the corresponding multiplicities in NN collisions at 200 GeV/c and n_K^{NN} is the average value over all kaon states. The second term of (3) is the result of expressing the contribution of the q_s-$\overline{q}_s$ strings in eq. (1) in terms of the kaon multiplicity in NN at 200 GeV/c - hence the reduction in its coefficient from $\overline{n}$-$\overline{n}_A = 29$ to 4*. Obviously these strings give the same number of K^-, K^+ and K_s^0. Using the experimental values** of n_i^{NN} given in ref. [11] :

$$n^{NN}_{\Lambda(\overline{\Lambda})} = 0.096\ (0.013)\ , \quad n^{NN}_{K^-(K^+)} = 0.17\ (0.24)\ , \quad n^{NN}_{K_s^0} = n^{NN}_{K} = 0.20 \tag{4}$$

* Computing the contribution of the short q-$\overline{q}$ strings at energies of a few hundreds of GeV/c is one of the main sources of numerical uncertainties in DPM. For this reason there is some uncertainty in the kaon multiplicities - which will also exist when a more sophisticated (Monte Carlo) treatment is used. This uncertainty is not present in $n_{\Lambda(\overline{\Lambda})}$.

** The typical errors in these numbers range from 10 % for K_s^0 and Λ to 30 %

we get

$$n_\Lambda = 2.3\ (9.4 \pm 1)\ , \quad n_{\overline{\Lambda}} = 0.31\ (2.2 \pm 0.4) \tag{5}$$

$$n_{K^-} = 4.9\ (6.9 \pm 0.4)\ , \quad n_{K^+} = 6.6\ (12.4 \pm 0.4)\ , \quad n_{K^0_s} = 5.6\ (10.5 \pm 1.7)\quad . \tag{6}$$

These numbers are much smaller than the experimental ones[12] given in brackets. The numerical results (2)-(6) are obtained considering only u and d quarks in the nucleon sea.

When also strange quarks are present, eq. (1) can be written as

$$n_i = 2\overline{n}_A\ N_i^{(qq)_v - q_v} + 2(n - \overline{n}_A) \left(\frac{S}{2+S} N^{q_s^S - \overline{q}_s^S} + \frac{2}{2+S} N_i^{q_s^{NS} - \overline{q}_s^{NS}} \right) \tag{7}$$

where the contribution of strange (q^S) and non-strange (q^{NS}) sea quarks are explicitly given (sea quarks have, of course, to be linked to sea antiquarks in all possible ways). We see from eq. (7) that the number of kaons will increase as a result of the fragmentation of q^S-$\overline{q}^S$ strings - since the fragmentation $s(\overline{s}) \to K^-(K^+)$ is larger than the corresponding one for non-strange quarks. We take this fragmentation function to be the same as $d \to \pi^-$ $(u \to \pi^+)$, since in both cases one has to pull out a $u\overline{u}$ $(d\overline{d})$ pair in the first string break-up. At CERN energies, the average mass of the q-$\overline{q}$ strings is so small that further break-ups are not possible. The same arguments leading from eq. (1) to (3), lead now from eq. (7) to

$$n_{K^{(i)}} = 24 n^{NN}_{K^{(i)}} + 4 \left(\frac{S}{2+S} n_\pi^{NN} + \frac{2}{2+S} n_K^{NN} \right) \tag{8}$$

which reduces to (3) for $S = 0$. Here $n_\pi^{NN} = 3.04$ is the pion multiplicity in nucleon-nucleon averaged over its three charge states[11]. The first (second) term

---

for $\overline{\Lambda}$. The corresponding errors in the SS multiplicities are easy to determine. However, the errors due to the uncertainties in the parameters of the model are much larger (see below).

inside the bracket corresponds to the contribution of q^S-$\overline{q}^S$ (q^{NS}-$\overline{q}^{NS}$) strings. The resulting values of the kaon multiplicities are now

$$n_{K^-} = 7.1 \ , \quad n_{K^+} = 8.8 \ , \quad n_{K^0_s} = 7.9 \quad . \tag{8'}$$

The multiplicity of K^- is now in agreement with experiment - while those of K^+ and K^0_s are still too low by about three units each. This difference is quite significant and cannot be explained in the framework of independent string models. Comparing (6) with (8'), we see that the strange sea quarks have produced an increase of 40 % in the kaon average multiplicity. For SU collisions the corresponding increase is almost a factor 2. This could perhaps explain the enhancement of the ratio $n_\phi/(n_\rho + n_\omega)$ observed experimentally[10][13] in central SU collisions.

Let us turn to Λ and $\overline{\Lambda}$ production. As already discussed, q-$\overline{q}$ strings cannot produce Λ-$\overline{\Lambda}$ pairs at CERN energies, and one has to introduce diquark pairs in the nucleon sea to account for its production. Following [2], I assume that their relative fraction α is the same as in the string breaking process, and I take the value $\alpha \sim 0.1$ from the JETSET code[14]. To first order in α, eq. (1) is then changed into[2] :

$$n_i = 2\overline{n}_A \, N_i^{(qq)_v - q_v} + (\overline{n} - \overline{n}_A) \left[(1-2\alpha) 2 N_i^{q_s - \overline{q}_s} + 2\alpha \left(N_i^{(qq)_s - q_s} + N_i^{(\overline{qq})_s - \overline{q}_s} \right) \right] \quad . \tag{9}$$

The last term in (9) corresponds to the contribution of strings with sea diquarks*. It will produce a substantial number of Λ-$\overline{\Lambda}$ pairs when the sea diquarks are either us or ds. I shall take the fragmentation functions us (ds) $\rightarrow \Lambda$ to be the same as uu (ud) $\rightarrow p$ - since in both cases one has to pull out a $d\overline{d}$ ($u\overline{u}$) pair in the first string break-up which produces the leading baryon. The number of Λ-$\overline{\Lambda}$ pairs

* It is easy to see that when using eq. (9) instead of eq. (1) (or eq. 7) the number of kaons is practically unchanged.

coming from the last term of eq. (9) is

$$\Delta n_{\Lambda(\overline{\Lambda})} = \alpha(\overline{n} - \overline{n}_A) \left[\frac{4S}{4+4S+S^2} n_p^{pp} + \frac{2}{4+4S+S^2} \, \frac{3}{2} n_\Lambda^{pp} \right] = 1.4 \quad . \qquad (10)$$

with $n_p^{pp} = 1.34$ and $n_\Lambda^{pp} = 0.096$[11]. The first term of eq. (10), which gives the most important contribution to Δn, is the result of the fragmentation of the strings with us, su, ds or sd diquarks at one end. The corresponding probability is $4S$ divided by the total weight $4 + 4S + S^2$ - where 4 is the weight of the non strange diquarks uu, dd, ud and du and S^2 is the one of the ss diquark. As explained above the average Λ multiplicity is in this case equal to n_p^{pp}. The second term corresponds to the fragmentation of strings containing ud and du diquarks*.

Adding (10) to (5), the $\overline{\Lambda}$ multiplicity is $n_{\overline{\Lambda}} = 1.7$, which is close to the experimental value - while $n_\Lambda = 3.7$ is still too low by more than a factor 2 (about six units).

Likewise, the extra Ξ^--$\overline{\Xi}^+$ pair production is given by

$$\Delta n_{\Xi(\overline{\Xi})} = \alpha(\overline{n} - \overline{n}_A) \left(\frac{S^2}{4+4S+S^2} n_p^{pp} + \frac{2S}{4+4S+S^2} \, \frac{3}{2} n_\Lambda^{pp} \right) = 0.22 \qquad (11)$$

The value of $n_{\overline{\Xi}}^{pp}$ has not been directly measured. From the ratio $n_{\overline{\Xi}}^{pp}/n_{\overline{\Lambda}}^{pp} = 0.06 \pm 0.02$[15], we deduce $n_{\overline{\Xi}}^{pp} \simeq 0.001$. We then have

$$n_{\overline{\Xi}} = 24 n_{\overline{\Xi}}^{pp} + \Delta n_{\overline{\Xi}} = 0.24 \quad , \qquad n_{\overline{\Xi}}/n_{\overline{\Lambda}} = 0.14 \quad . \qquad (12)$$

---

* Only diquark fragmentations that occur without diquark breaking have been included in eqs. (10)-(12). The factor $\frac{3}{2}$ in the second term of (10) and (11), is due to the fact that only two (out of the three diquarks of the proton) can fragment into Λ without breaking. Almost identical results are obtained when the "pop-corn" diquark breaking mechanism is taken into account. For instance, the contribution to the second term of eq. (10) of uu (dd) $\to \Lambda$ diquark breaking fragmentation, is approximately compensated by a corresponding decrease of the factor $\frac{3}{2}$.

Somewhat larger values of $n^{pp}_{\Xi}/n^{pp}_{\Lambda}$ have been measured in e^+e^- and $\overline{p}p$ at high energies. A recent measurement from the E735 coll.[16] suggests a value as large as 0.25. This places the ratio (12) in the range $0.14 \div 0.18$. Notice that this ratio is rather insensitive to variations of S and/or α. It is also practically independent of the process : one gets $0.15 \div 0.19$ in SAu. This value has to be compared with the experimental numbers : 0.20 ± 0.03 in SW from the WA85 coll.[17] and 0.127 $\pm$ 0.022 in SPb from NA36 coll.[18] (the latter in a limited range of y and $p_\perp$). A similar value of this ratio was found in [2].

The same argument allows to determine the extra number of Ω-$\overline{\Omega}$ pairs, which is given by

$$\Delta n_{\Omega(\overline{\Omega})} = \alpha(\overline{n} - \overline{n}_A)\frac{S^2}{4+4S+S^2}\frac{3}{2}n^{pp}_{\Lambda} = 0.02 \quad , \tag{13}$$

leading to a ratio $n_{\overline{\Omega}}/n_{\Xi} \sim 0.1$.

It is important to note that n^{pp}_p and n^{pp}_{Λ} in Eqs. (10)-(13) have to be taken at the reduced energy $\sqrt{s/3} \sim 11$ GeV. This is due to the presence of three diquarks, which share most of the momentum of the nucleon. This is of little consequence for the average SS multiplicities - since the values of n^{pp}_p and n^{pp}_{Λ} measured at 69 GeV/c[19] are consistent with those at 200 GeV/c[11]. However, this fact is crucial to understand the rapidity distributions : the Λ-$\overline{\Lambda}$ pairs will be concentrated in the region $|y^*| < Y^*_{MAX} \sim 2$, as observed experimentally[12].

As discussed above, the number of missing Λ's is about six units and those of missing K^+ and K^0_s are about three units each. The most obvious mechanism that produces extra Λ, K^+ and K^0_s, without changing the number of the other particles, is the final state interaction

$$\pi + N \rightarrow K + \Lambda/\Sigma \tag{14}$$

where π and N are co-moving secondaries. It is clear that the process (14) is very favorable to produce extra Λ's. Indeed its gain is proportional to the density of N

(much larger than the one of Λ's), times the density of pions - which is even larger. By strangeness conservation, kaons will be produced exactly in the same amount (equally shared between K_s^0 and K^+) - while K^- and $\overline{\Lambda}$ are not produced. Notice that the losses of K's and Λ's resulting from the crossed processes

$$\pi + \Lambda \rightarrow K + N \quad (a) \quad , \qquad K + N \rightarrow \pi + \Lambda \quad (b) \quad , \tag{15}$$

with cross-sections comparable to the one of the direct process (14), produce small effects in the final balance of produced particles. For instance, the loss of Λ's in (15a) relative to its gain in (14) is suppressed by the ratio of Λ over N densities. Moreover the loss of Λ's in (15a) and its gain in (15b) tend to compensate one another. The same is true for the balance of kaons. Therefore, I shall concentrate on the gain of K's and Λ's resulting from (14)*. This gain is proportional to the product of π's and N's densities times the cross-section of process (14). This cross-section, suitably averaged over the momentum distributions of the colliding particles near the production threshold, will be denoted by $< \sigma >$. Following Ref. [20], we have

$$\frac{dn_\Lambda}{dy} = \int d^2 s \frac{dn_{\pi_-}}{dy d^2 s} \; \frac{dn_p}{dy \; d^2 s} 3 < \sigma > \ell n \left[\tau + \tau_0 \right) / \tau_0 \right] \tag{16}$$

where τ_0 is the formation proper time, τ the time during which the final state interaction takes place and $d^2 s$ a differential transverse area. (For a collision at zero impact parameter, $|\vec{s}|$ measures the distance between this differential area and the axis determined by the centers of two colliding nuclei). The factor three comes from the product of three pion times two nucleon species divided by a factor 2

---

* Probably the real situation is more complicated with some extra gain of kaons due to $\pi\pi \rightarrow K\overline{K}$ and some extra loss of kaons (and gain of strange baryons and antibaryons) due to the strangeness exchange reactions ($KN \rightarrow \pi\overline{Y}$ and $\overline{K}N \rightarrow \pi Y$) which have a large cross-section at threshold[6][22]

which is due to the fact that the cross-sections for $\pi^+ p$ and $\pi^- n$ are negligeably small.

For SS collisions at $b \sim 0$, one gets by using Gaussian nuclear profiles*,

$$\frac{dn_\Lambda}{dy} = \frac{3 < \sigma >}{\pi R^2} \frac{dn_{\pi^-}}{dy} \frac{dn_p}{dy} \ell n \left[\tau + \tau_0 \right) / \tau_0] \tag{17}$$

where R is the r.m.s. radius of Sulfur. I take $\tau_0 \sim 1$ fm and $\tau + \tau_0 \sim \tau_f \sim 4$ fm, based on interferometry measurements which indicate a very short time of particle emission and a freeze out time of 4 fm[21]. For the value of $< \sigma >$, I take $< \sigma > = 1.5$ mb. (The sum of $\pi N \to K\Lambda$ plus $\pi N \to K\Sigma$ cross-sections at their maxima is 1.5 mb[22]. Beyond the maximum these cross-sections decrease sharply but quasi two-body processes convert this sharp decrease into a mild increase). Using the experimental data of the NA35 coll.[23] for the dn_p/dy and dn_{h^-}/dy rapidity densities (the latter multiplied by $n_{\pi^-}^{NN}/n_{h^-}^{NN}$), one gets from eq. (17)

$$\Delta n_\Lambda = 2\Delta n_{K^+} = 2\Delta n_{K_s^0} = 6.2 \quad . \tag{18}$$

A practically identical result is obtained using the values of the π^- and p densities computed in DPM.

To summarize, adding the values obtained above, the average multiplicities of strange particles in SS collisions at 200 GeV/c per nucleon are :

$$n_{K^-} = 7.1 \quad , \qquad n_{K^+} = 11.9 \quad , \qquad n_{K_s^0} = 11.0 \quad ,$$

$$n_\Lambda = 9.9 \quad , \qquad n_{\overline{\Lambda}} = 1.7 \quad , \qquad n_{\Xi} = 0.24 \div 0.30 \quad .$$

The ratio $n_{\Xi}/n_{\overline{\Lambda}} = 0.14 \div 0.18$ is practically the same in S-S and S-Au collisions.

In conclusion, the scenario of strangeness enhancement presented above is based on two mechanisms : the presence of strange quarks and diquarks in the nucleon

* At fixed b, one has : $dn/dy\ d^2s \propto \overline{n}_A(b,s) \propto T_A(b-s)\sigma_{NA}(s)$, where $\sigma_{NA}(s) = 1 - (1 - \sigma T_A(s))^A$ and $T_A(b) = \exp(-b^2/r^2)/\pi r^2$ with $r^2 = 2R^2/3$.

sea, controlled by the parameters $S \sim 0.5$ and $\alpha \sim 0.1$, and the final state interaction of co-moving secondaries ($\pi N \to K\Lambda/\Sigma$), controlled by the parameter $< \sigma > \ell n(\tau + \tau_0)/\tau_0$. There are uncertainties in the values of these parameters. The value $S \sim 0.5$ is used in DIS[3] but there is also indirect evidence for such a large fraction of strange quarks from πN scattering[24]. The value of the strangeness suppression factor in the string breaking process is believed to be somewhat smaller - a value 0.4 is suggested by the Λ/p ratio at mid-rapidities measured at Fermilab[16]. Using $S = 0.4$, instead of $S = 0.5$, reduces the final numbers of Λ and $\overline{\Lambda}$ computed above by only 0.15 units - and those of kaons by 0.4. There are also uncertainties in the precise formulation of the final state interaction as well as in the value of the parameter that controls it. Moreover, the above scenario is consistent only if all other rescattering processes[6] contributing to the gain and loss of strangeness in a hadronic gas approach give small enough effects.

The introduction of diquarks in the nucleon sea has some common features with string fusion[4][5]. It is, on the contrary, in sharp contrast with a phase transition scenario at the partonic level (QGP), considered by many authors[25] - where the production rate of strange quarks increases in the deconfined phase[22]. Actually, in the present approach the strange quarks and diquarks are an <u>intrinsic</u> property of the nucleon wave function and therefore the parameters S and α are expected to be universal, i.e. independent of (the centrality of) the process and of its energy. A detailed study of strange particle production in various processes, including predictions for $PbPb$, is in progress. It will be very interesting to compare them with the forthcoming results on strangeness enhancement from lead beam experiments at CERN.

Acknowledgements

It is a pleasure to thank A. Kaidalov for interesting discussions and suggestions on the role of final particle interaction. I also thank A. Bialas, K. Fialkowski, A. Kouider, A. Krzywicki, C. Merino, J. Ranft, C. Pajares and J. Tran Thanh Van for interesting discussions. An early discussion with J. Casado on the introduction of sea diquarks in DPM is also acknowledged.

References

[1] A. Capella, U. Sukhatme, C. I. Tan and J. Tran Thanh Van, Phys. Rep. 236 (1994) 225.

[2] J. Ranft, A. Capella, J. Tran Thanh Van, Phys. Lett. B320 (1994) 346 ; H. J. Möhring, J. Ranft, A. Capella, J. Tran Thanh Van, Phys. Rev. D47 (1993) 4146 (the calculations in these papers are based on the DPMJET and DTNUC codes).

[3] A.D. Martin, R. G. Roberts and W. J. Stirling, preprint RAL-94-005 (DTP/94/3).

[4] N. Armesto, M.A. Braun, E.G. Ferreiro and C. Pajares, University of Santiago de Compostela, preprint US-FT/16-94. References to earlier papers on string fusion can be found in G. Gustafson, Nucl. Phys. A 566 (1994) 233c.

[5] RQMD : H. Sorge, R. Matiello, A. von Kectz, H. Stöcker and W. Greiner, Z. Phys. C47 (1990) 629 ; H. Sorge, M. Berenguer, H. Stöcker and W. Greiner, Phys. Letters B289 (1992) 6.

[6] P. Koch and J. Rafelski, Nucl. Phys. A444 (1985) 678.

[7] QGSM : A. Kaidalov, Phys. Lett. B117 (1982) 459 ; A. Kaidalov and K. A. Ter-Martirosyan, Phys. Lett. B117 (1982) 247. For the corresponding Monte Carlo code see N. S. Amelin et al., Phys. Rev. C47 (1993) 2299.

[8] VENUS : K. Werner, Nucl. Phys. A566 (1994) 477c ; Phys. Rep. 232 (1993) 87 ; preprint HD-TVP-94-6.

[9] A. Capella, C. Pajares, V.A. Ramallo, Nucl. Phys. B241 (1984) 75 ; A. Capella, J. Kwiecinski, J. Tran Thanh Van, Phys. Lett. B108 (1982) 347.

[10] HELIOS/3 coll. : A. Manzoni, Nucl. Phys. A566 (1994) 95c.

[11] M. Gazdzicki and Ole Hansen, Nucl. Phys. A528 (1991) 754.

[12] NA35 coll. : T. Alber et al., Z. Phys. C64 (1994) 195.

[13] NA38 coll. : C. Baglin et al., Phys. Lett. B259 (1991) 62 ; R. Ferreira, Nucl. Phys. A544 (1992) 623c.

[14] B. Andersson, G. Gustafson and T. Sjöstrand, Physica Scripta 33 (1985) 574 ; T. Sjöstrand, CERN-TH 6488/92.

[15] AFS coll. : T. Åkesson et al., Nucl. Phys. B246 (1984) 1.

[16] E765 coll. : T. Alexoupoulos et al., Phys. Rev. D46 (1992) 2773.

[17] WA85 coll. : E. Quercig, Nucl. Phys. A566 (1994) 321c ; D. Evans, ibid p. 225c.

[18] NA36 coll. : J. M. Nelson, Nucl. Phys. A566 (1994) 217c.

[19] V. V. Amomsov et al., Nuovo Cimento 40A (1977) 237. L. H. Blumenfeld et al., Phys. Lett. 45B (1973) 528.

[20] P. Koch, U. Heinz and J. Pitsut, Phys. Lett. B243 (1990) 149.

[21] NA35 coll : G. Roland, Nucl. Phys. A566 (1994) 527c ; D. Ferenc, Proceedings 29th Rencontres de Moriond (1994) ed. J. Tran Thanh Van ; NA44 coll. : T.J. Humanic, Nucl. Phys. A566 (1994) 115c ; S. Panday, Proceedings Rencontres de Moriond, ibid.

[22] B. Koch, B. Muller and J. Rafelski, Phys. Rep. 142 (1986) 167. A compilation of $\pi N \to K\Lambda/\Sigma$ and $KN \to \pi\Lambda$ cross-sections is given in Appendix B.

[23] NA35 coll. : J. Bartke et al., Z. Phys. C48 (1990) 191 ; D. Röhrich, in Nucl. Phys. A566 (1994) 35c.

[24] B. Ioffe and M. Karliner, Phys. Lett. B247 (1990) 387 and references therein.

[25] J. Lettessier, A. Tounsi, U. Heinz, J. Sollfrank and J. Rafelski, Phys. Rev. Lett. 70 (1993) 3530 and preprint PAR/LPTHE/92-27R ; N. Heinz, Nucl. Phys. A566 (1994) 205c ; K. Redlich, J. Cleymans, H. Satz and E. Suhonen, Nucl. Phys. A566 (1994) 391c and references therein ; M. Gaździcki and St. Mrówczyński, Z. Phys. C49 (1991) ; H. W. Barz, B. L. Friman, J. Knoll, H. Schulz, Nucl. Phys. A484 (1988) 661 ; K. Geiger, Phys. Rev. D48 (1993) 4129. See also ref. [7].